HST's Radiation Environment Inferred from Charge-Collection Modeling of NICMOS Darkframes

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Acknowledgments

- Thanks are due to many for this work:

- My collaborators, especially George Gee and Jim Pickel and Robert Reed

- NGST

- Ken Label

NGST and the Early Universe

- The Next Generation Space Telescope's (NGST) mission is to probe the extremities of the Universe in the infrared
  - Earliest moments: Big Bang and the formation of the first stars
  - The highest energies: Black holes and active galactic nuclei
  - The most distant objects: Quasars
- Instruments must meet very stringent requirements
  - Sensitivity to low-energy IR photons (0.5-30 microns)
    - requires cryogenic operation
  - Long integration times to detect faint sources (>1000 s)
  - High sensitivity (read noise requirement<10 electrons; goal is <3)
- In short, NGST instruments will be excellent radiation detectors.
  - Radiation that would normally only contribute to TID can contaminate data
- The need for unprecedented precision poses concerns:
  - Primary and secondary environments more uncertain at low energies.
  - Infrared Space Observatory saw higher-than-expected backgrounds.

Become an Expert on the Unknown—Quick!

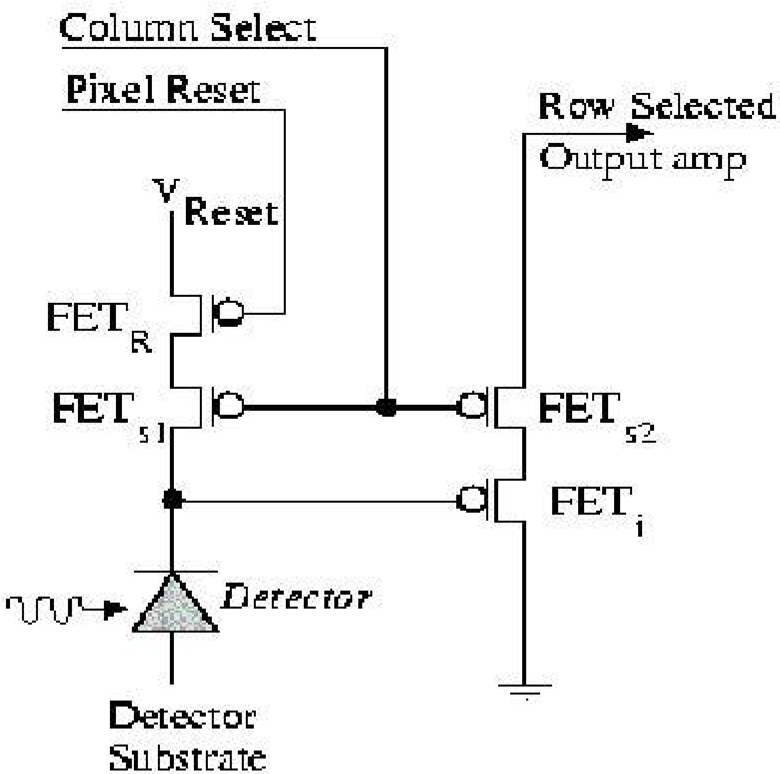
- Hubble's Near Infrared Camera and Multi-Object Spectrometer (**NICMOS**) is a natural place to turn for experience.
  - Detectors are photovoltaic $Hg_xCd_{(1-x)}Te$— similar to a NGST technology
  - Ideal datasets and known radiation environment
- NICMOS darkframe data taken with filter wheel in closed position
  - No illumination of detectors
  - Several data sets taken at different positions in orbit and after different passes through the South Atlantic Anomaly
  - Purpose of data was calibration
    - Understanding dark currents
    - Cosmic ray rejection algorithms
      - Note: only 70% of cosmic rays actually get rejected
  - Use the detector itself as an environmental monitor

Outline

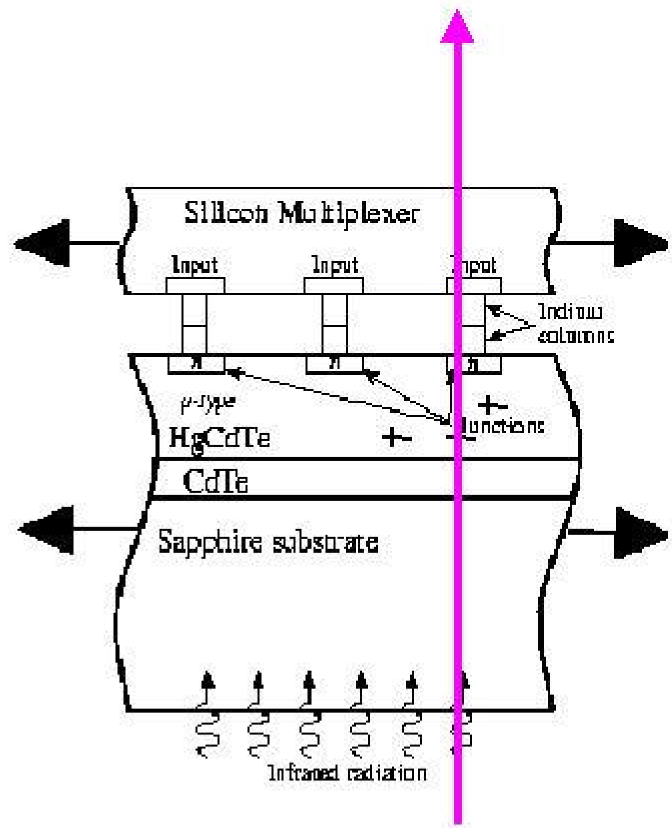
- NICMOS detectors and their radiation response
- NICMOS Darkframe Data Sets
- Data Processing and Analysis
- Model of Detector Charge collection
- Implications of Charge-Collection Model for NICMOS
- Results

VII. Conclusions

NICMOS Detectors



NICMOS Unit Cell

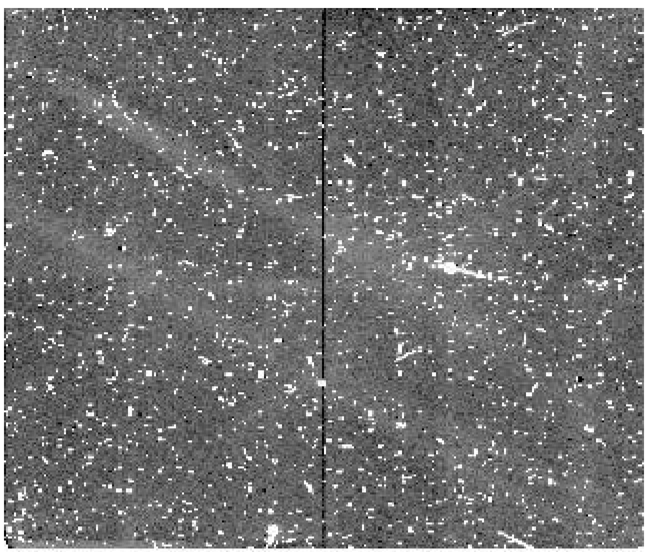


Radiation Effects in NICMOS Detectors

- Effects of radiation in photovoltaic infrared detectors
  - Prompt Direct ionization
    - Primary particles—protons and electrons; higher energy means lower LET
      - Random in location and usually time
    - Secondary particles—mainly protons and electrons; lower energy, high LET
      - May be spatially and temporally correlated with a primary strike… or not
  - Radioactivation
    - Low energy electrons and gamma rays (alphas probably too short range)
      - Rate decays exponentially with time.
  - Persistence
    - At 77 K, charge trapped in shallow traps results in increased dark current; magnitude decreases exponentially with time (time constant ~160±60 sec.)
  - Phosphorescence
    - Light given off when trapped charge is released. Very low charge yield, but may result in a diffuse contamination.

NICMOS Darkframes

- Purpose is calibration of detectors and cosmic-ray rejection routine
  - Dark current measurement
  - Cosmic ray rejection
- Datasets include
  - Up to 17 frames with exposure times from 0.3-256 seconds

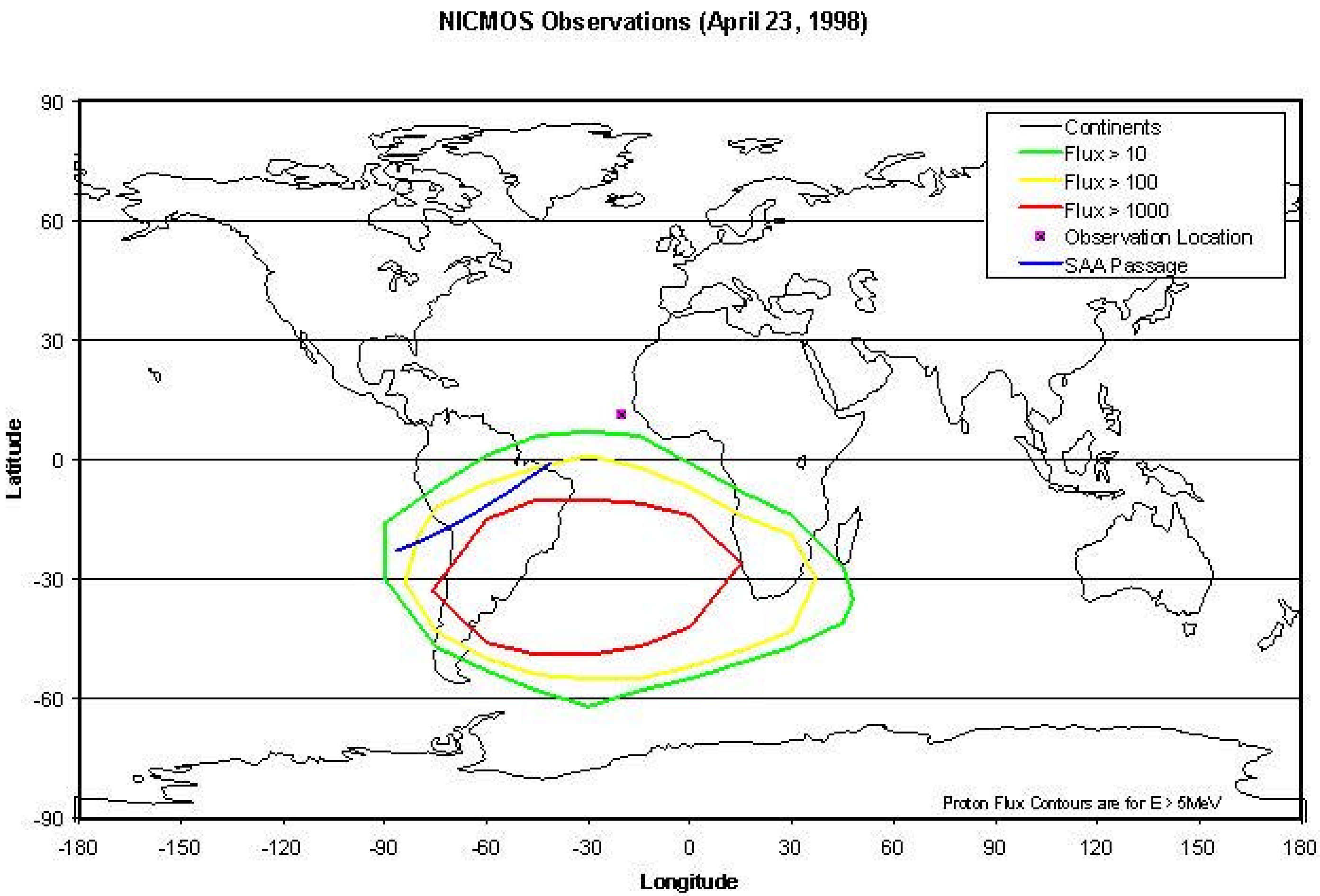


•Darkframes represent a range of prior radiation exposure and time since last exposure.

Table I: SAA Exposures

Date	SAA exposure	Duration of exposure	Time Since Exposure
3/25/98	Severe	30 minutes	35 minutes
4/23/98	Moderate	15 minutes	6 minutes
5/20/98	Light	10 Minutes	39 minutes
7/16/98	Very Light	8 minutes	6 minutes
8/12/98	Light	10 minutes	336 minutes

Darkframes Example I



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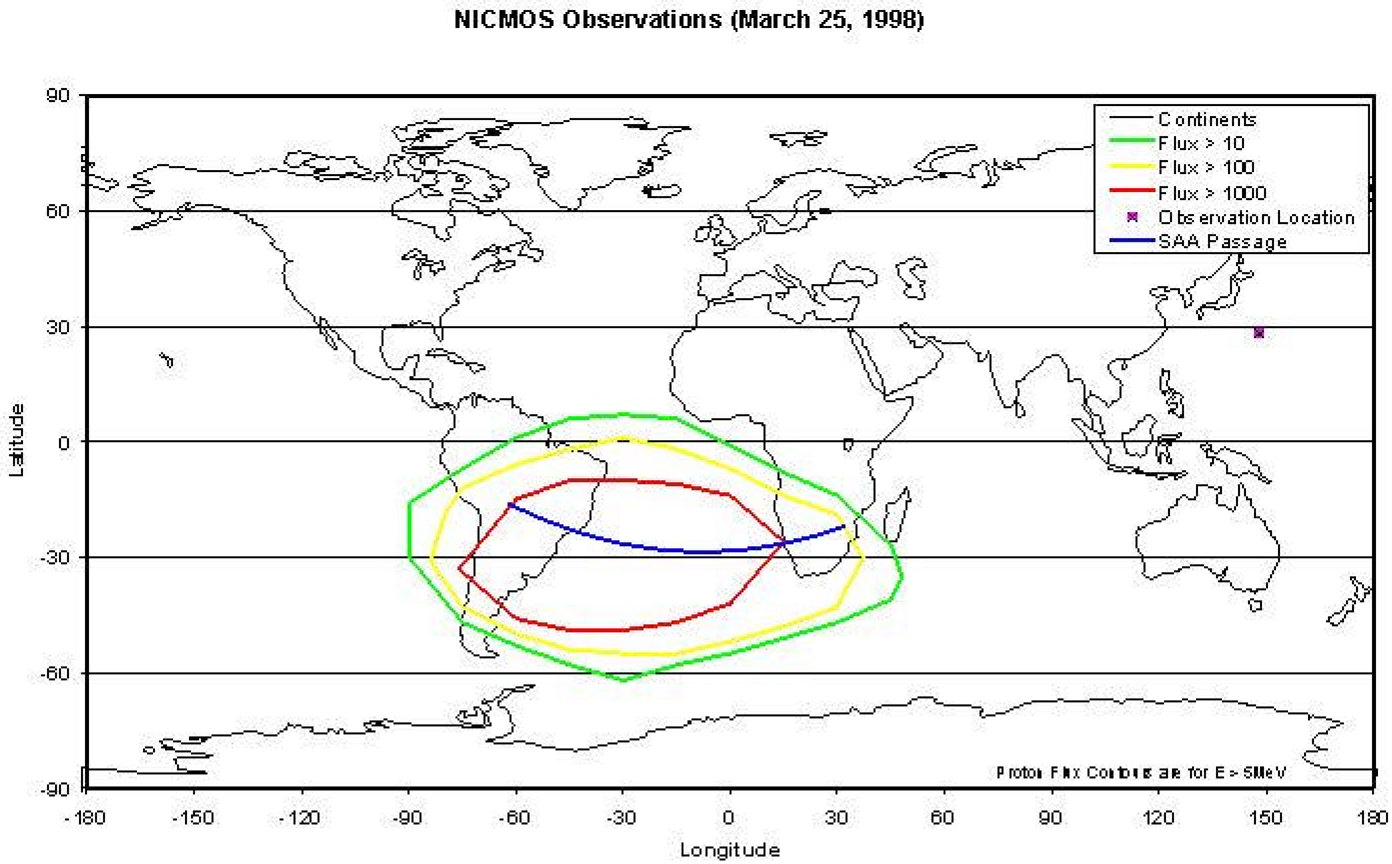
Darkframes Example II



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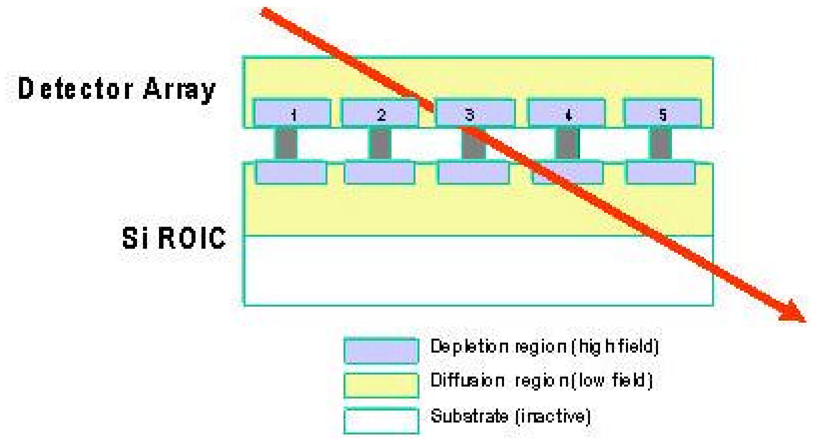
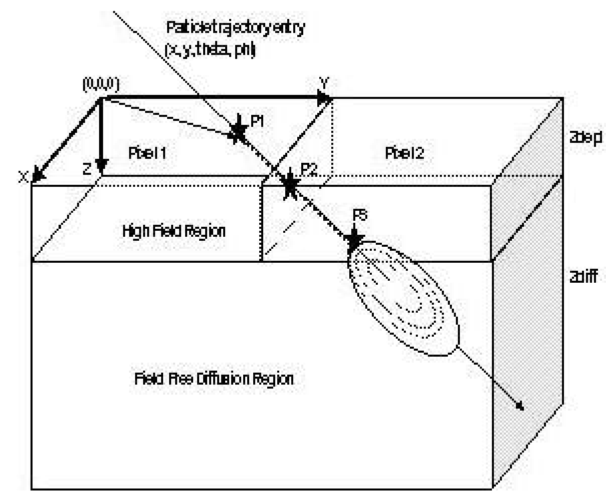
Darkframe Processing and Analysis

- Data processing involves:
  - Identifying pixels with high values
  - Correlating pixel contents over time and with nearest and more distant neighbors.
    - Identifies hot pixels and gives some information about particle trajectory and possible associated secondary particles.
    - Looking for evidence of persistence.
  - Identifying probable path lengths when possible
    - Resolution is limited by pixel pitch and depth of charge collection (diffusion-layer thickness)
    - Particles incident at glancing angles provide more information.
  - Assembling “hits” from individual pixel readings.
  - Looking at temporal and spatial correlations in the data
- With 5 datasets, 17 frames per dataset and >65000 pixels per frame, resulting data is unwieldy$\rightarrow$ >5 Gbits and growing

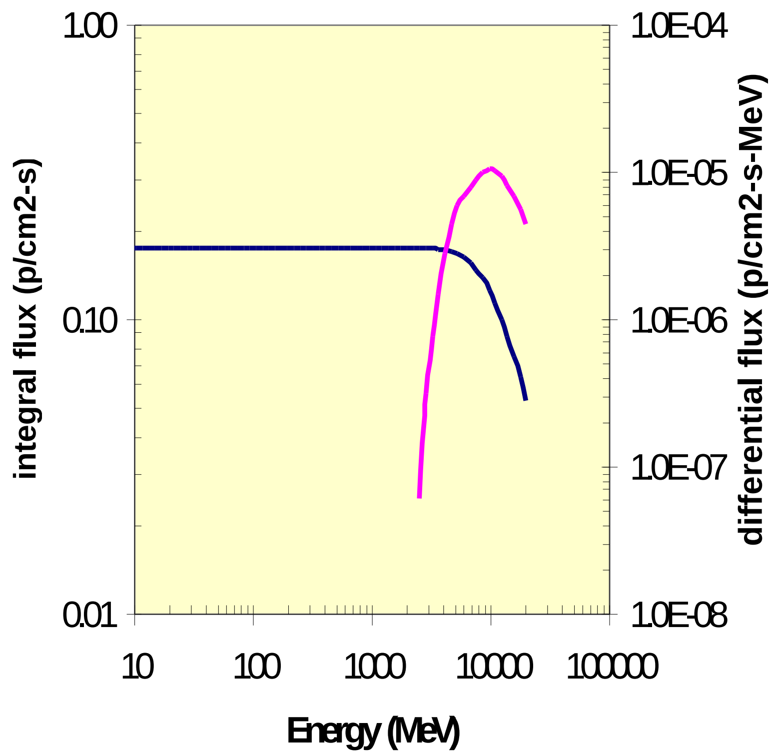
IR Detector Model

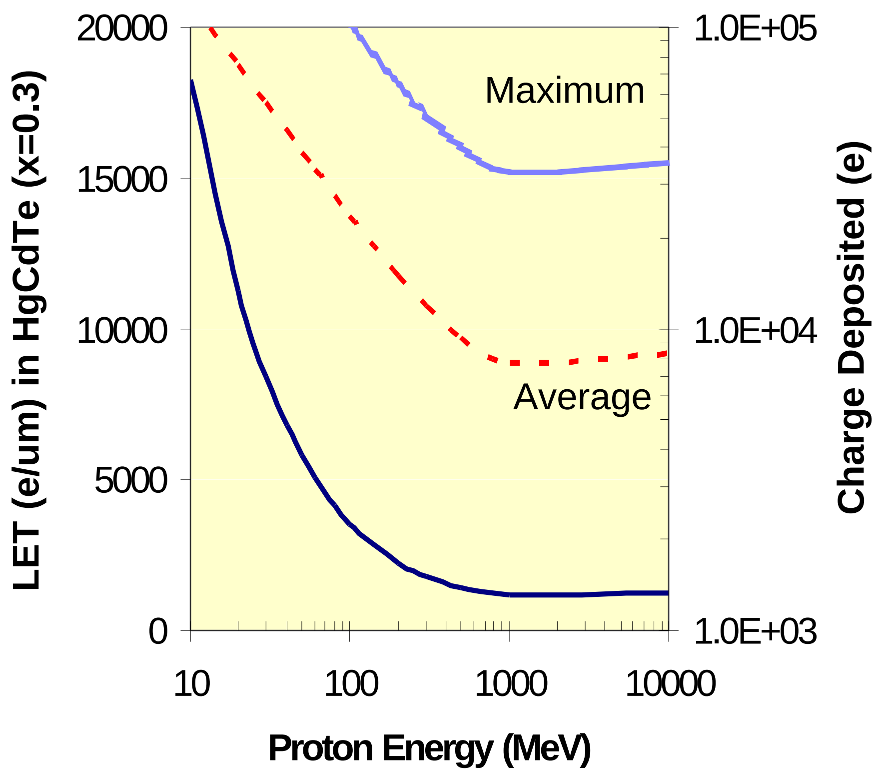
- IR detector model has 2 different charge-collection regions:
  - HgCdTe detector should dominate
  - Silicon readout integrated circuit
- Note that charge is also collected by two different mechanisms:
  - Drift in the high-field depletion region
  - Diffusion in the field-free region below
  - Diffusion region much thicker
    - diffusion can dominate
- Model is generalized from
  S. Kirkpatrick, IEEE Elect. Dev. Lett., Vol. ED-26, p. 1742.
- **See the talk by Jim Pickel (D-1, 3:40)**



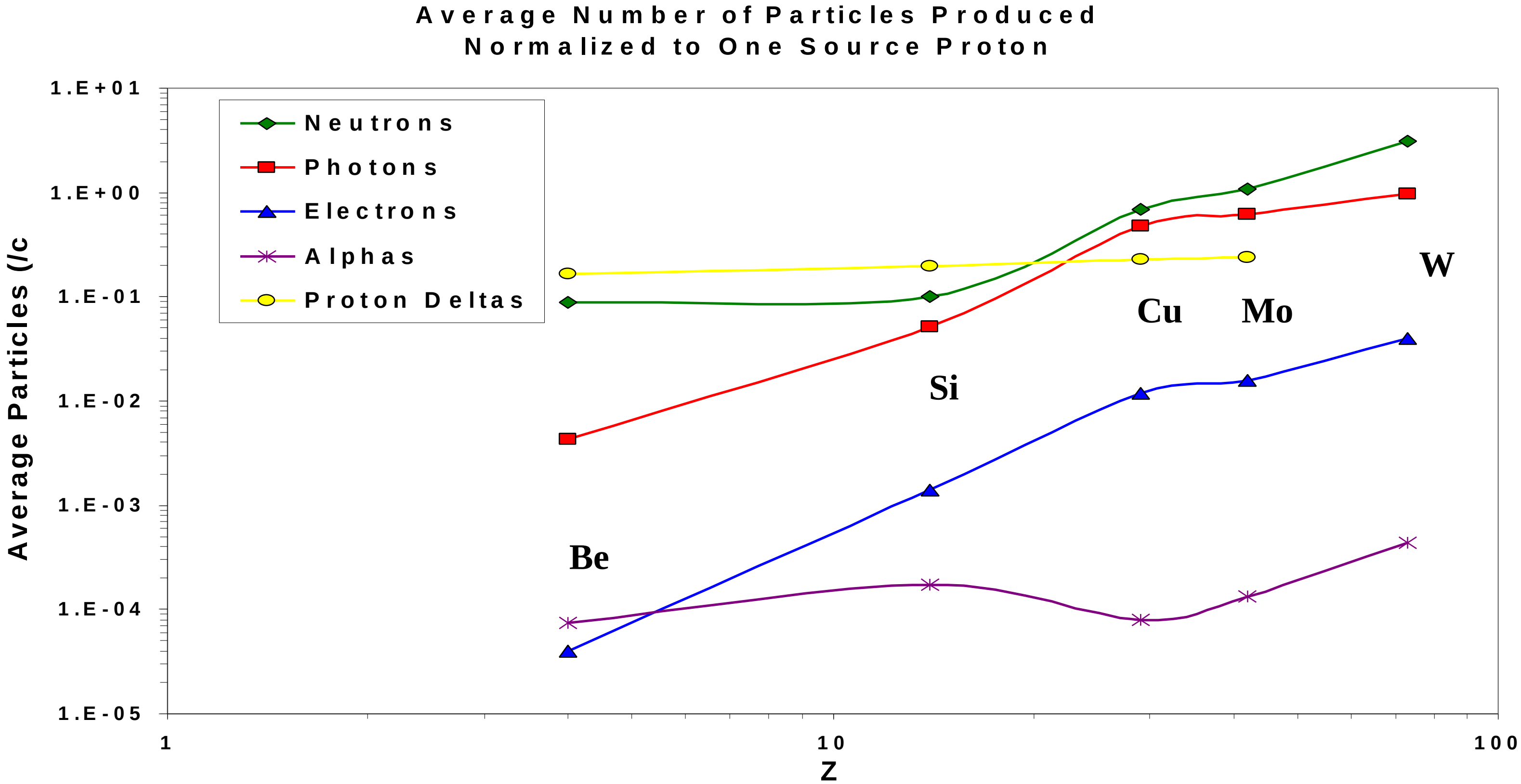


Primary Environment and Charge Deposition





Secondary Environment



Modeled with NOVICE Monte Carlo Program.

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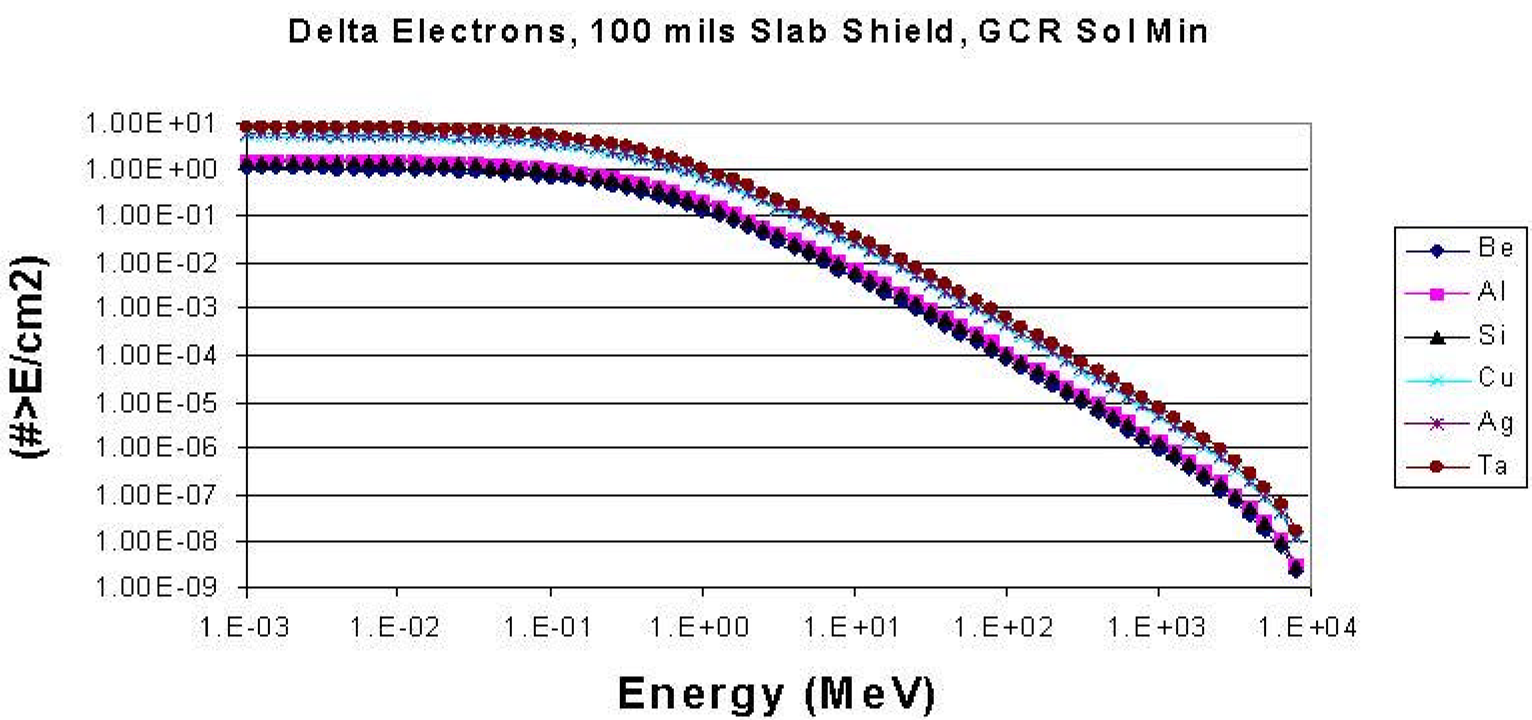
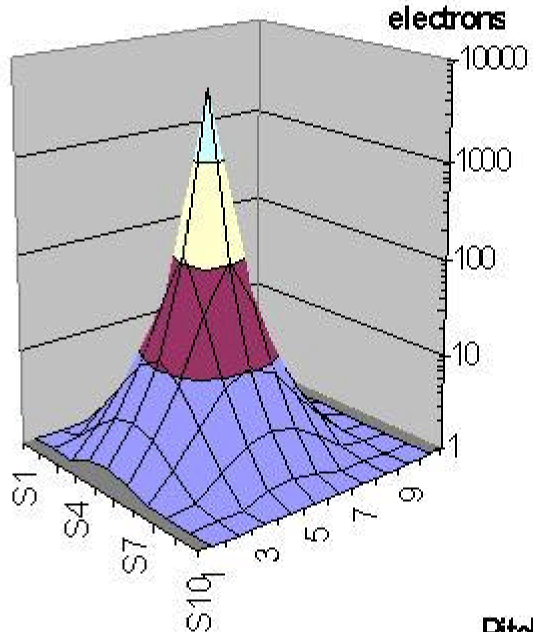
Secondary Environment (Cont'd)

Note that Most of the deltas have energies from ~100 keV to ~1 MeV $\Rightarrow$ LET of ~ 1000-2000 electrons/micron.

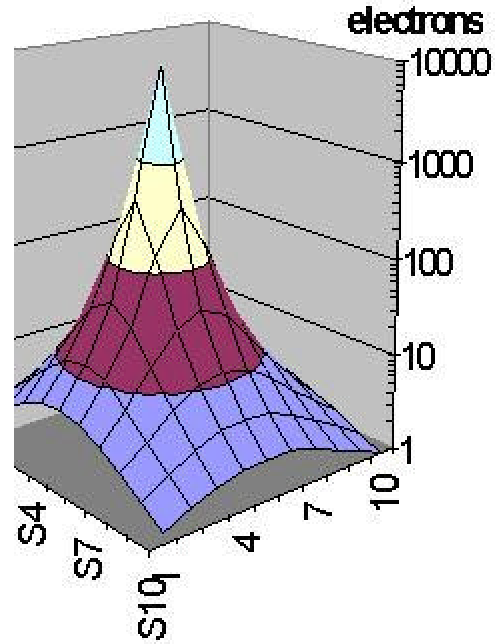


Implications of Model for NICMOS—Diffusion Length

Ldiff = 5 um



Ldiff = 10 um



Pitch = 30 um

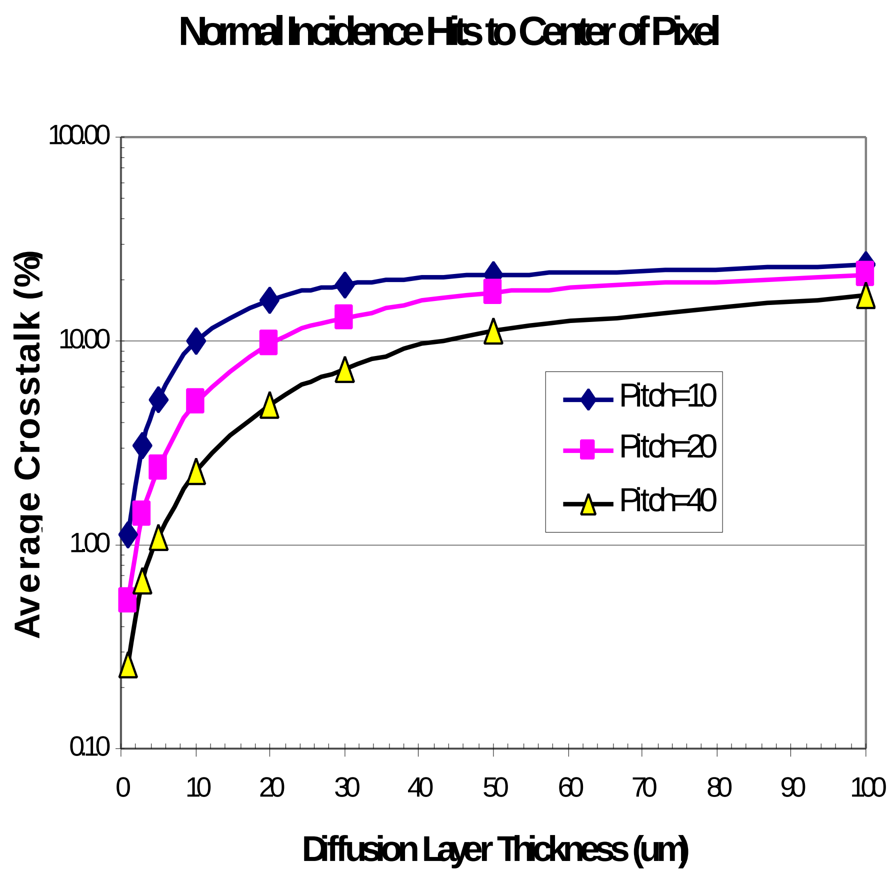
Zdepl = 1 um

Cross-Talk and Diffusion Layer

Crosstalk between adjacent Pixels depends on pixel pitch and diffusion-layer thickness.

Selecting adjacent pixels with nearly equal counts allows us to estimate both crosstalk and diffusion-layer thickness.

Best estimate is about 1% crosstalk, implying a diffusion layer thickness of 5-10 microns for 40 micron-pitch pixels.



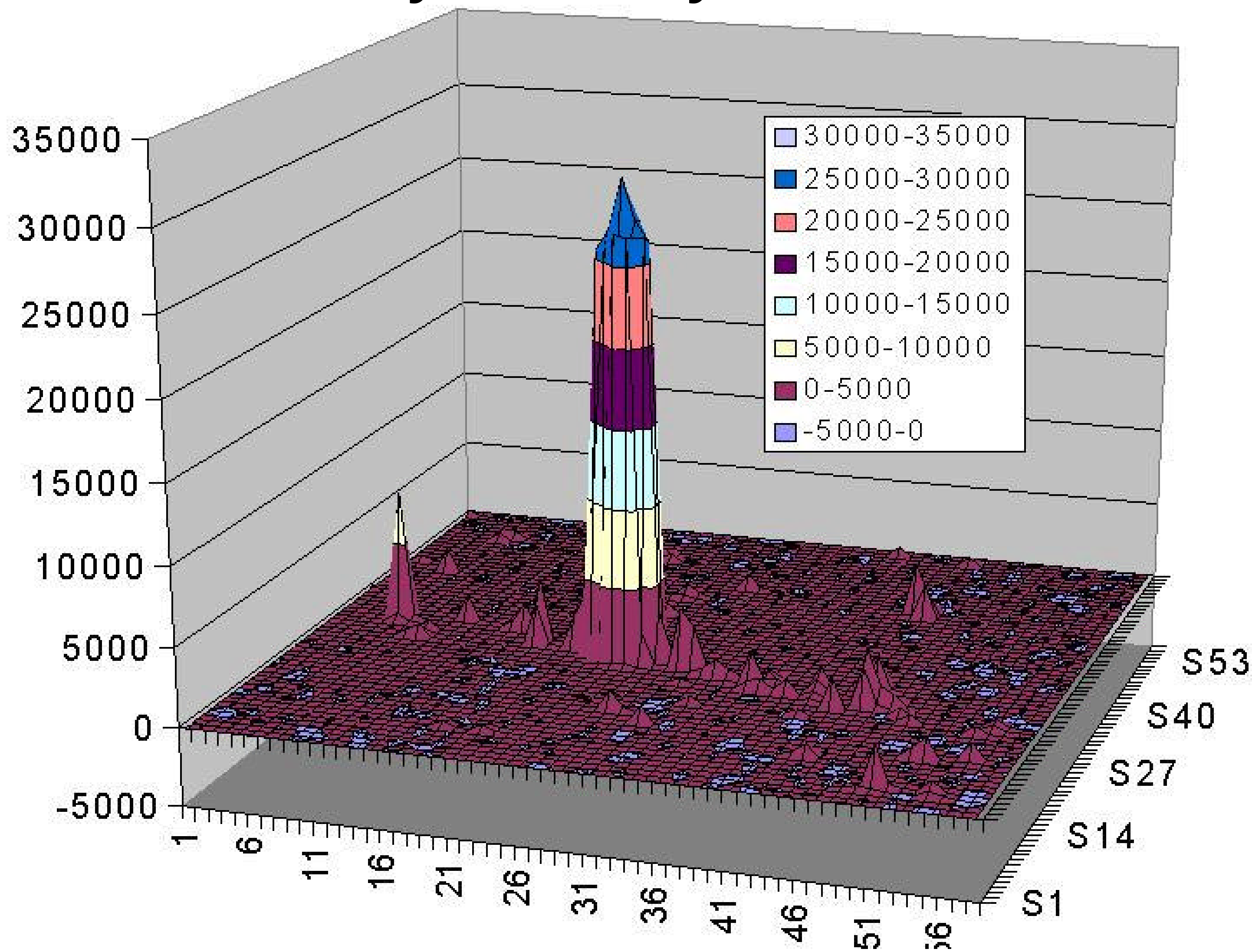
Comparison of Results to Model

- GCR environment predicts an average of 35-40 proton hits
  - most proton hits yield ~8000-15000 electrons in the struck pixel.
  - Maximum is ~35000 electrons, but with low probability

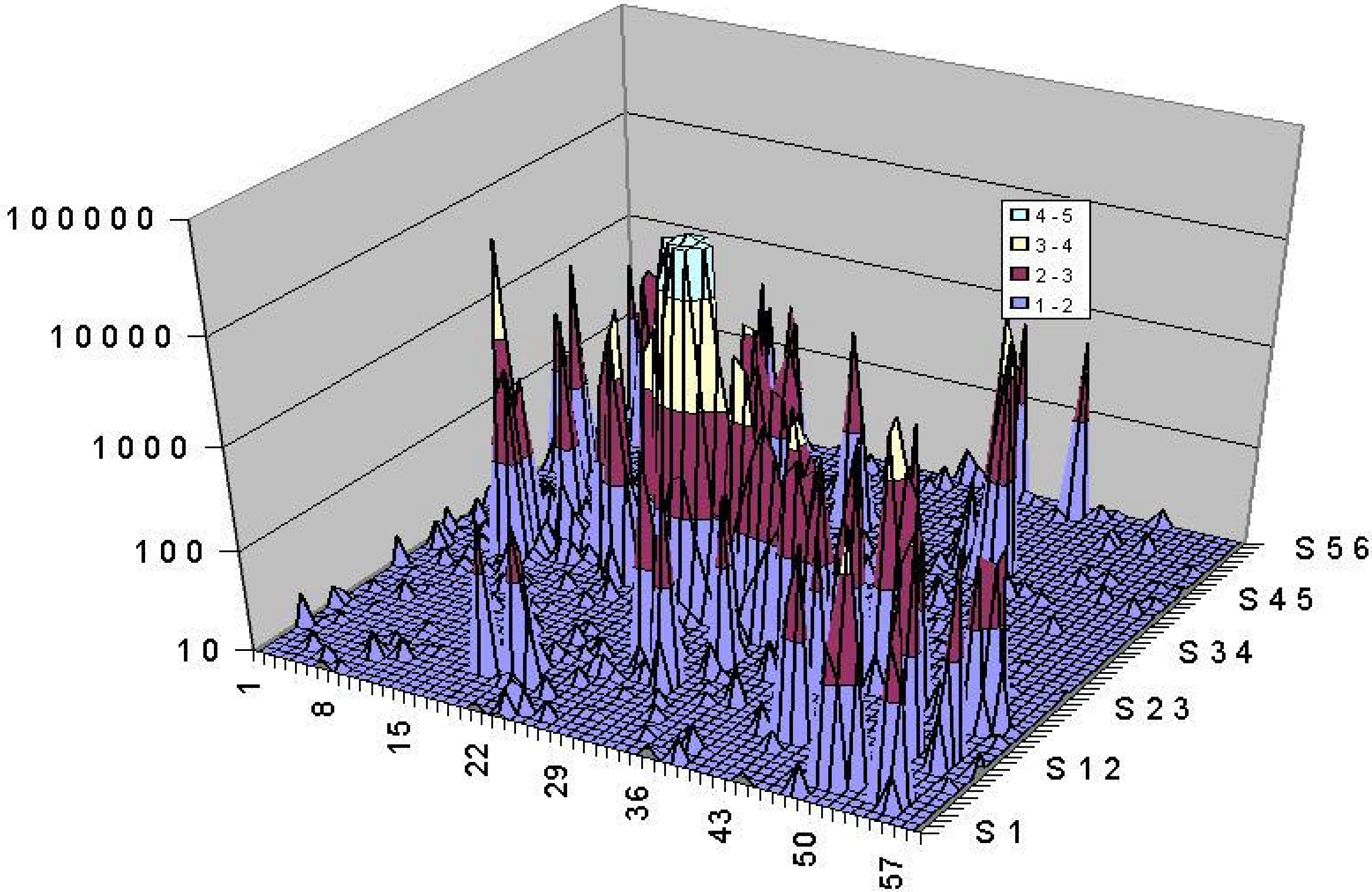
Electrons	3/25/98	4/23/98	5/20/98	7/16/98	8/12/98	Average
8000-15000	29	32	47	24	44	35
15000-35000	18	21	26	22	33	24
>35000	5	5	5	4	11	6

- What is responsible for these hits?
  - GCR protons account for most hits in the 8000-35000 electron range
    - ~50% of "proton" hit generate>8000 e^- in 2 or more pixels
    - ~20% of protons also generate deltas; may also contribute
    - These two facts could account for frequencies seen in this count range
  - Pixels with >35000 e^- must be low-energy protons or light ions
  - No evidence of systematic time dependence in these signals

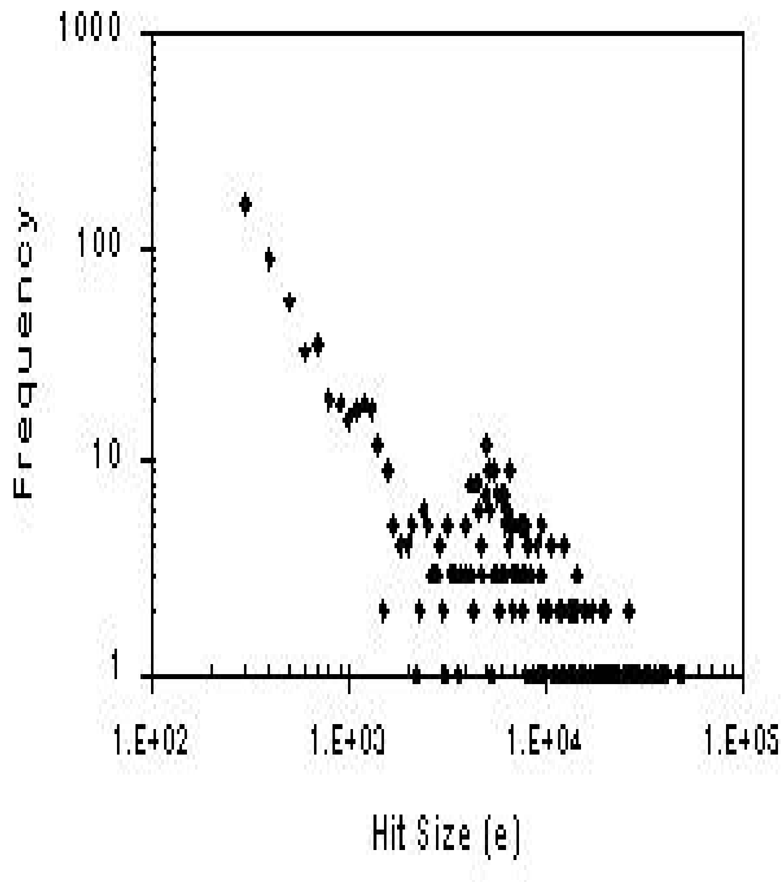
Secondary-Primary Correlations

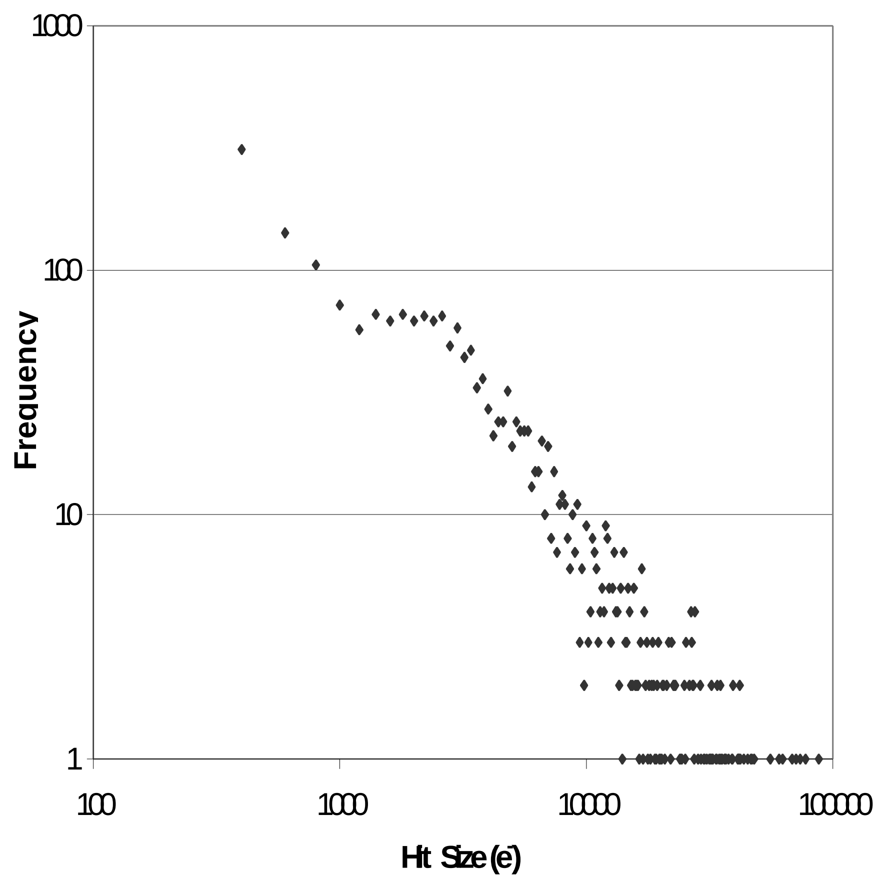


Secondary-Primary Correlations



Comparison of Hit Size





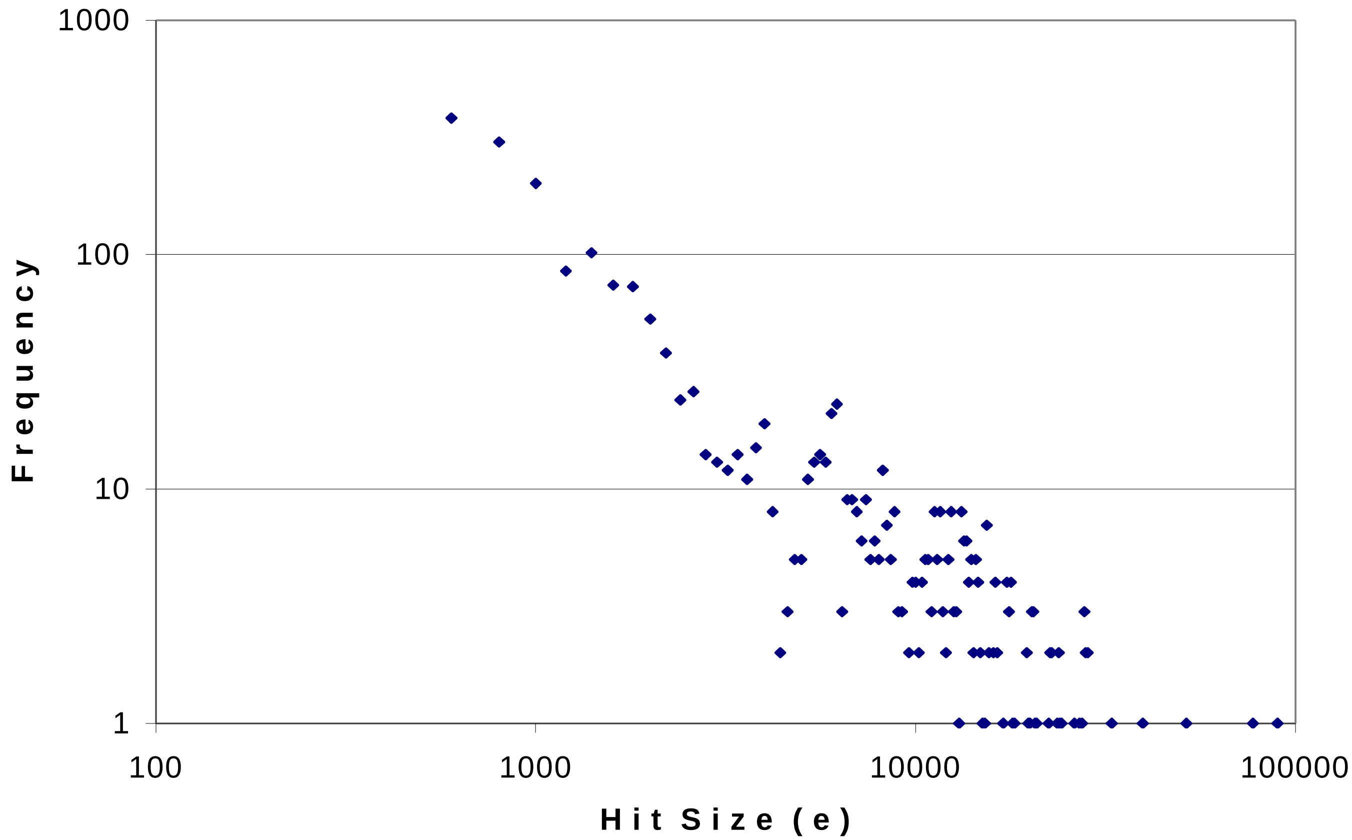
Hit Size: Model vs. Measurements

- Agreement is good at low electron counts (<1500 e^-)
- Also good in the range expected for proton hits (~8000-15000 e^-)
- Large events are not inconsistent with minimum-ionizing alpha strikes
  - Also not inconsistent with moderate-energy protons
- Two main areas of inconsistency
  - High end of proton range (~15000-35000 e^-):
    - May be understood as multi-pixel hits and/or deltas
    - No clear time dependence
  - 1500-5000 electron count range: discrepancy is ~6x
    - No clear time dependence
    - Inconsistency worse for frames with vary large events
    - Range-limited secondaries??
    - Effects of Si ROIC or need for model refinement?
- At low electron count (<1000), may be evidence of time dependence
  - Some datasets exhibit downward trend with time. Some do not.

Conclusions and Future Work

- A model of charge collection and sharing is essential to understanding radiation-induced backgrounds in IR detectors
  - Diffusion plays a very important role in charge collection
  - Understanding the charge yield can allow probable identity (or identities) of incident particle to be established.
- Backgrounds appear to be higher than expected in some cases
  - 8000-35000 e^- : protons and high-energy secondaries (deltas, etc.) ~15%
  - 1500-5000 e^- : discrepancy is significant, ~6x
    - Causes could be range limited secondaries or issues with model
- Future work
  - Investigate 1500-5000 e^- range
  - Examine possible associations of secondaries with primary hits
  - Refine pattern recognition for particle ID
  - Contribute to development of cosmic-ray rejection algorithms

A New, Improved NICMOS



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